

Land Cover Maps for Regional Climate Modelling in West Africa – A comparison of Datasets

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Abstract. Land cover is related to a number of biogeophysical land surface properties and therefore has an influence on surface fluxes of water and energy. In many climate impact studies, land cover maps are used to estimate land surface properties that are needed to describe relevant land surface processes. Currently, several global or continental land cover maps are available which can be used for this purpose. These maps have been created from remote sensing data of different instruments and years, using different classification methodologies and legends. Discrepancies between these maps can lead to differences in attribution of land surface properties and subsequently to inconsistent results of climate studies. Here, four global and continental land cover maps are harmonized and compared for West Africa. After harmonization, selected land surface properties (seasonal minimum and maximum of leaf area index (LAI), albedo, roughness length and fraction of vegetation cover) are derived based on a standard dataset which is commonly used during data preparation for the Weather Research and Forecasting (WRF) model. The resulting spatial patterns of land surface properties exhibit major discrepancies in regions of agricultural land use, in savannas and in the transition zones between savannas and deserts of West Africa.

Keywords: Land cover, land surface properties, climate modelling, West Africa, LCCS.

1. Introduction

Land cover is closely related to a number of biogeophysical land surface properties such as albedo, vegetation structure or surface roughness. Previous studies have demonstrated that land cover and related land surface properties have an influence on the spatio-temporal patterns of water and energy fluxes, e.g. [1]. Thus, land cover maps are crucial input information in many climate modelling studies where they are primarily used for the parameterization of land surface processes. In this context, land surface properties are usually estimated for each class of a land cover map to describe their spatial variability in the geographical region of interest. For instance, in the current version of a widely-used atmospheric model, the Weather and Research Forecasting (WRF) model [2], standard values of various land surface properties are provided for the classes of two global land cover maps. Several global or continental, medium resolution land cover maps are available which could generally be used for the parameterization of land surface processes. These maps have been created from data of different sensors and years, using different classification methodologies and legends. Especially for mixed classes, considerable differences between these maps have been identified at global scale, e.g. [3], [4].

In West Africa, large parts of natural vegetation have been converted into small-scaled agricultural areas as a consequence of high population pressure, and therefore, land cover patterns

are often heterogeneous. Additionally influenced by high and persistent cloud coverage, West Africa poses a challenge for accurate land cover mapping based on optical remote sensing data. Such discrepancies in land cover maps of West Africa which are due to varying mapping approaches and due to regional, methodological challenges can influence the output of climate impact analyses for the region.

In this study, four global and continental land cover maps are harmonized and compared for the area of West Africa. After harmonization, selected land surface properties (i.e. seasonal minimum and maximum of leaf area index (LAI), albedo, roughness length and fraction of vegetation cover), are derived from these maps based on a standard dataset which is typically used for parameterization of land surface processes in the WRF model. The delineated spatial patterns of land surface properties in West Africa exhibit considerable discrepancies in regions of agricultural land use, in savannas, and in transition zones between savannas and deserts.

2. Material and methods

2.1. Study region

The study region West Africa is bounded by the Atlantic Ocean in the west and south and extends to approximately 11°E and 19°N. The region is characterized by a strong precipitation gradient from humid conditions in the south to an arid climate in the north. Accordingly, the region comprises a wide range of vegetation units including evergreen rainforest in the south, various types of savanna vegetation and finally sparsely vegetated areas and deserts in the north. The research area is characterized by a high population density and related land use has formed small-scaled agricultural patterns.

2.2. Land cover datasets

Four land cover maps are considered in this study. The Global Land Cover 2000 (GLC 2000) is composed of 19 harmonized regional datasets [5]. Here, the African regional dataset [6] is analyzed. GLC 2000 is created from daily SPOT 4-VEGETATION data from November 1999 to December 2000 with a spatial resolution of 1 km. The legend of the African GLC 2000 dataset is based on the Land Cover Classification System (LCCS) [7]. Within the West African study region, it comprises 23 classes.

Globcover 2005 consists of both a global and several regional datasets. In this study, the regional product of Africa is considered. This map is based on MERIS data of the period December 2004 to June 2006 with a spatial resolution of 300 m. The land cover classes are delineated in a stratified approach using both supervised and unsupervised classification techniques [8]. The LCCS-based legend differentiates 38 classes in West Africa.

The global University of Maryland (UMD) Land Cover map is created using a global classification approach based on decision trees [9]. The map is generated from AVHRR data of the years 1992/93 at a spatial resolution of 1.1 km. In the study region, the UMD Land Cover map includes 12 classes.

The global MODIS Land Cover Type dataset (MOD12Q1, collection 5) is a standard MODIS land product with updates for every year. It is created using global ensemble decision trees and post-classification adjustments [10]. In this study, the dataset for the year 2001 is selected. It is based on MODIS data and has a spatial resolution of 1 km. The IGBP (International Geosphere-Biosphere Programme) legend of the MODIS Land Cover product discriminates 14 classes in West Africa.

2.3. Harmonization of land cover maps

Due to differences in their legend systems, a direct comparison of the mentioned land cover maps is not possible. Therefore, the land cover classes were harmonized based on LCCS principles, following the general approach described by [11]. The final, harmonized legend comprises the land cover types proposed in [4], reduced by three classes which are not relevant for West Africa (Table 1). The legend focuses on a set of common classifiers which are mainly related to life form and canopy cover, leaf type and longevity, and surface type (e.g. bare soil, water, built-up, and vegetation). A lower threshold for the canopy cover of tree-classes is set to 10-15% and areas with a vegetation cover below 15% are assigned to ‘barren’. Mosaic and mixed classes are, wherever possible, attributed to a single dominant class.

For both the UMD and the MODIS dataset, the class translation of [4] could be used without modification. For the regional African GLC 2000 however, the existing translation table was slightly changed: the class ‘open grassland’ was translated to ‘barren’ as in the regional African dataset of GLC 2000, the vegetation cover for this class is defined to be 5-15%. All other legend items were translated according to [4]. For the Globcover 2005 map, a detailed, LCCS-compatible description of land cover classes is available, such that in this case, a straightforward translation was possible (Table 1).

For spatial comparison, the generalized land cover maps were resampled to a common regular grid of 1 km x 1 km using the nearest neighbour method. In case of Globcover, a spatial aggregation was performed where each grid cell was attributed with the dominant land cover class (mode) of the original dataset.

Table 1. Generalized land cover classes, their description using LCCS classifiers and the respective classes of the Globcover 2005 regional African dataset.

Generalized land cover class	LCCS Label	Globcover 2005 Regional African classes
Evergreen Broadleaf Trees	A12-A3.A20.B2.XX.D1.E1 and A12-A3.A10.B2.XX.D1.E1 and A24-A3.A20.B2.XX.D1.E1	40, 41, 42, 160, 161, 162, 170
Deciduous Broadleaf Trees	A12-A3.A20.B2.XX.D1.E2 and A12-A3.A10.B2.XX.D1.E2	60
Mixed/Other Trees	A12-A3.A20.B2 and A24-A3.A20.B2	110
Shrubs	A12-A4.A20.B3	130, 131, 134
Herbaceous vegetation	A12-A2.A20.B4	140, 141
Cultivated and managed vegetation/ agriculture (incl. Mixtures)	A11 and A23	11, 12, 13, 14, 15, 16, 20, 21, 30, 31, 32
Other shrub/herbaceous vegetation	A24.A2 and A24.A4	120, 180, 181, 185
Urban/built-up	B15	190
Barren	B16 and A12-A1.A14 and A12-A2.A14	150, 151, 152, 200, 201, 202, 203
Water	B27-A1 and B28-A1	210

2.4. Translation of land cover maps into land surface properties

In many climate modelling studies, land surface properties are estimated based on land cover maps. Usually, these properties are assumed to be homogeneous within a land cover class and invariant at inter-annual time scales. In this study, land surface properties are estimated based on a standard dataset which is commonly used together with the MODIS map during data preparation for the WRF model. In a first step, this dataset is aggregated to the generalized land cover classes. The classes are aggregated in the same way as for legend harmonization (Table 2, column 1 & 2). In case several classes have to be merged to one generalized class, the arithmetic mean of the

respective land surface property value is calculated. Table 2 lists the resulting mean values for maximum LAI, minimum LAI, maximum albedo, minimum albedo, minimum roughness length and fraction of vegetation cover. Using this dataset, the selected land surface properties are estimated for each of the harmonized land cover maps.

Table 2. Adapted dataset for estimating land surface properties from generalized land cover maps.

MODIS class	Generalized land cover class	Maximum LAI [-]	Minimum LAI [-]	Maximum albedo [%]	Minimum Albedo [%]	Minimum roughness length [m]	Fraction of vegetation cover [%]
Evergreen Broadleaf Forest	Evergreen Broadleaf Trees	6.48	3.08	12	12	0.5	95
Deciduous Broadleaf Forest	Deciduous Broadleaf Trees	3.31	1.85	17	16	0.5	80
Mixed Forests	Mixed/Other Trees	4.3	1.2	25	21	0.12	67
Woody Savannas							
Savannas							
Closed Shrublands	Shrubs	3.1	0.5	30	24	0.01	70
Open Shrublands							
Grasslands	Herbaceous vegetation	2.90	0.52	23	19	0.1	80
Permanent wetlands	Other shrub/herbaceous vegetation	5.72	1.75	14	14	0.3	60
Croplands	Cultivated and managed vegetation/agriculture (incl. Mixtures)	5.0	1.9	23	18	0.05	80
cropland/natural vegetation mosaic							
Urban and Built-Up	Urban/built up	1.0	1.0	15	15	0.5	10
Barren or Sparsely Vegetated	Barren	0.1	0.75	38	38	0.01	1
Water	Water	0.01	0.01	8	8	0.0001	0

3. Results

3.1. Agreements and disagreements between harmonized land cover maps

The harmonized 1 km land cover datasets are illustrated in Figure 1. The maps show clear discrepancies, but at the same time similarities between GLC 2000 and Globcover, and between MODIS and UMD Land Cover become apparent. The overall spatial agreement and disagreement between the four harmonized datasets is shown in Figure 2. Full consistency between all maps is given for 22.5% of the study area (white). Major agreements are found in the Sahara and for some patches of evergreen forest in the south of West Africa. 32% of the study area is assigned to two different classes (light grey), 39.5% to three different classes (dark grey). For 6% of the West African land surface, none of the maps agree (black).

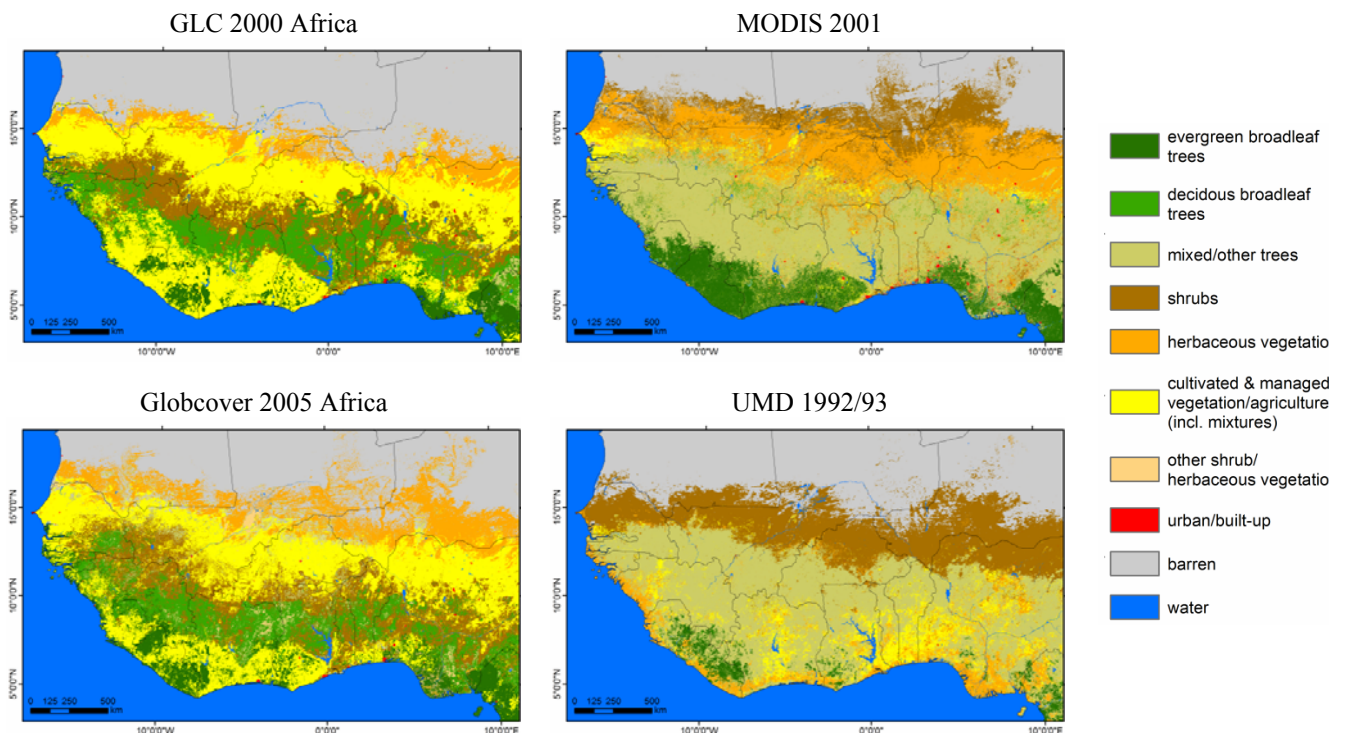


Figure 1: Land cover maps of West Africa, translated to the harmonized legend (Table 1) and transferred to the same regular grid of 1 km resolution.

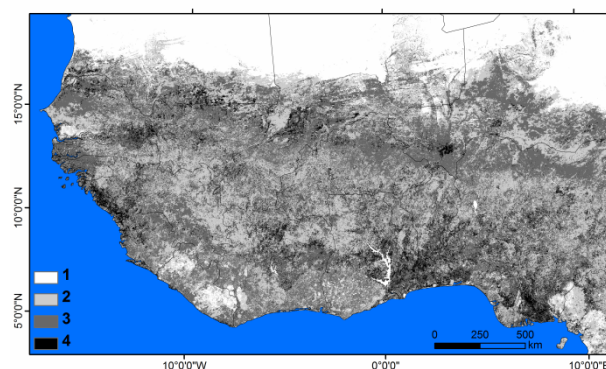


Figure 2: Spatial agreement between the four harmonized land cover datasets. The colors refer to the number of different land cover classes assigned in the datasets. Full agreement between all maps is shown in white, while black indicates full disagreement, i.e. four different land cover classes in the four considered maps.

Spatial class agreements and disagreements for pair-wise combinations of maps are displayed in Figure 3. In addition, the agreement between maps is quantified based on Kappa coefficients [12]. Again, the general consistency between GLC 2000 and Globcover with respect to spatial distribution of the major land cover classes is apparent. These maps show highest agreements with a Kappa coefficient of 0.57. Moderate agreement is also found between the MODIS and UMD datasets, with the exception of herbaceous vegetation and agriculture (Kappa coefficient: 0.39). In contrast, the spatial class distribution of GLC 2000 and Globcover show considerable discrepancies when compared to MODIS and UMD Land Cover (Kappa coefficients ≤ 0.27).

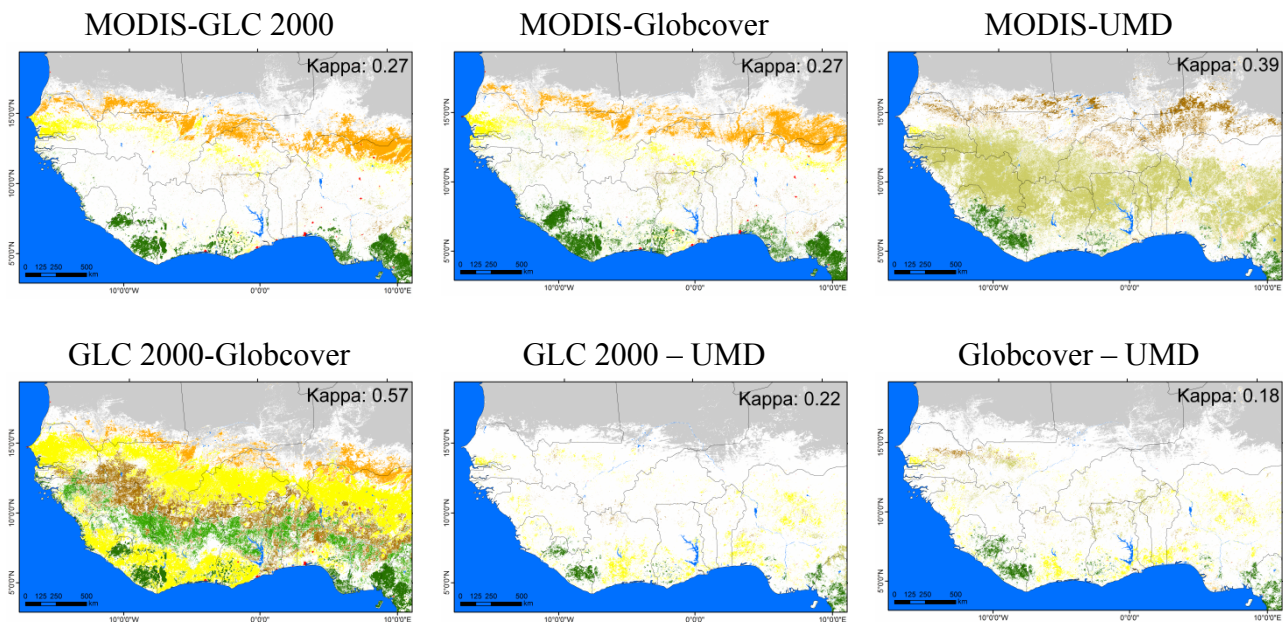


Figure 3: Spatial agreements between pairs of the generalized maps and corresponding Kappa coefficients. Areas of disagreement are shown in white; areas of agreement are shown in colour. For the colour code see Figure 1.

The total areas covered by each land cover class in the four maps are shown in Figure 4. The area per class is again similar for GLC 2000 and Globcover on the one hand and MODIS and UMD on the other hand. Most striking differences in the total expansion are found for the classes ‘mixed/other trees’ and ‘cultivated and managed’. The former class is widespread in UMD and MODIS Land Cover (32-33%) and negligible in GLC 2000 and Globcover (< 3%). The latter is extensively attributed in GLC 2000 and Globcover (26-26%) while it is of minor importance in the UMD and MODIS datasets (< 7%).

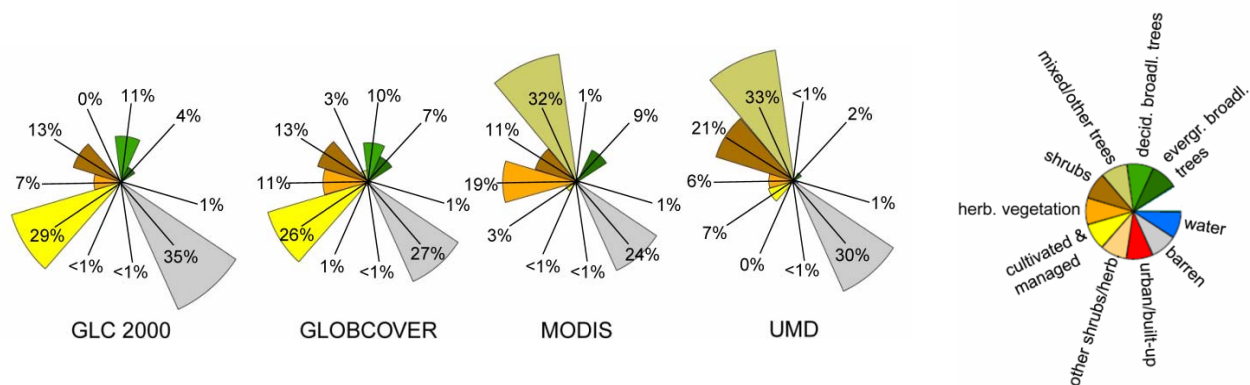


Figure 4: Area per land cover class and map. The radii of the plot segments correspond to the area assigned to a land cover class. Numbers give the proportion of a class in the total map area.

The inter-comparison analyses reveal regions of high discrepancies where land cover classifications are problematic, and regions of high agreement where the class assignment is likely to be (though not definitely) correct. However, it has to be noted that the comparative analyses do not allow stating which map shows highest accuracies.

Similar to the presented discrepancies between medium resolution land cover maps for West Africa, inconsistencies have been identified in other comparative studies of other maps at global scale, e.g. [3], [4]. Validation exercises of Globcover and MODIS Land Cover Type (MCD12Q1) showed comparably high confusions for mixed and heterogeneous classes [8], [10]. These types of

land cover classes are widespread in the study region, particularly in the savanna zones and in agricultural areas. General methodological problems in land cover mapping and discrepancies in class definition for heterogeneous landscapes might thus be a reason for some of the strong disagreements found in our analyses.

As the selected land cover maps represent different years, land cover/use change could also be a reason for the discrepancies in classifications, at least for the more consistent maps GLC 2000 and Globcover on the one hand and UMD and MODIS Land Cover on the other hand. However, implausible land cover change trajectories do not support this assumption. Examples are the strong increase in forest cover in both pairs of maps and the appearance of grassland in the northern savanna belt of the MODIS dataset which is not present in the UMD Land Cover.

3.2. Spatial distribution of selected land surface properties

Subsequently it was examined how the use of the four land cover maps influences the spatial patterns of land surface properties when estimated using Table 2. Figure 5 exemplarily illustrates absolute differences in seasonal maximum LAI (top) and fraction of vegetation cover (bottom) based on MODIS and GLC 2000. In line with the good map agreement for barren areas and partly for evergreen broadleaf trees, the land surface properties agree in the Sahara and in evergreen forest areas. However, strong discrepancies for both variables are found in Sudano-Sahelian zone. Here, the maps inconsistently assign the classes ‘barren’, ‘herbaceous vegetation’ and ‘shrubs’ which show major differences with respect to land surface properties in the used dataset (Table 2). South of this zone, the fraction of vegetation cover is more consistent and differences between maps are mostly below 20% of green vegetation cover. Maximum LAI shows comparably stronger deviances. Differences in maximum LAI range between 3 in the Sahelian zone and -3 in the Sudano-Sahelian zone.

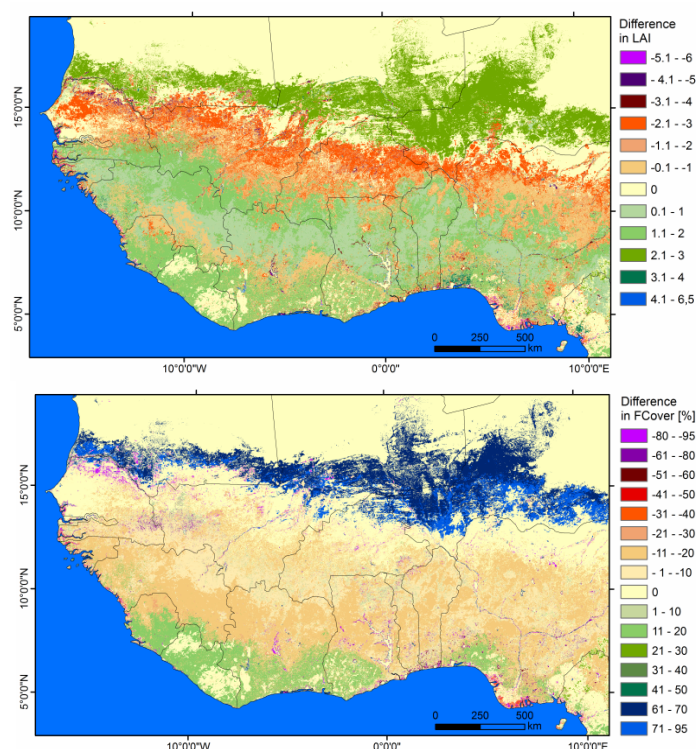


Figure 5: Differences in seasonal maximum LAI (top) and fraction of vegetation cover (bottom) as derived on the basis of MODIS Land Cover compared to GLC2000. Positive/negative differences result from higher/lower values in the dataset derived from MODIS Land Cover when compared to GLC 2000.

In accordance with the latitudinal distribution of land cover types in West Africa, (dis)agreements between land cover maps (Figure 3) and delineated land surface parameters (Figure 5) also show latitudinal patterns. Average latitudinal values for each land surface property are shown in Figure 6. South of approximately 7°N, the latitudinal averages of land surface variables are similar for all land cover maps except for the UMD dataset. In the zone between approximately 7°N and 14°N, dataset dependent discrepancies in magnitude and in latitudinal trends are stronger. In this zone, differences are particularly distinct for land surface properties which are directly related to vegetation structure (i.e. LAI and roughness length). Here, similar to the agreements between the land cover maps (Figure 1 & 3), agreements are apparent for GLC 2000 and Globcover on the one hand and UMD and MODIS on the other hand. North of approximately 14°N conditions change and similarities are stronger for UMD and GLC 2000 on the one hand and Globcover and MODIS on the other hand. In the region north of 14°N, the plots reveal a northward shift of several land surface properties (maximum LAI, maximum and minimum albedo and fraction of vegetation cover) derived on the basis of Globcover and MODIS when compared to UMD and GLC 2000.

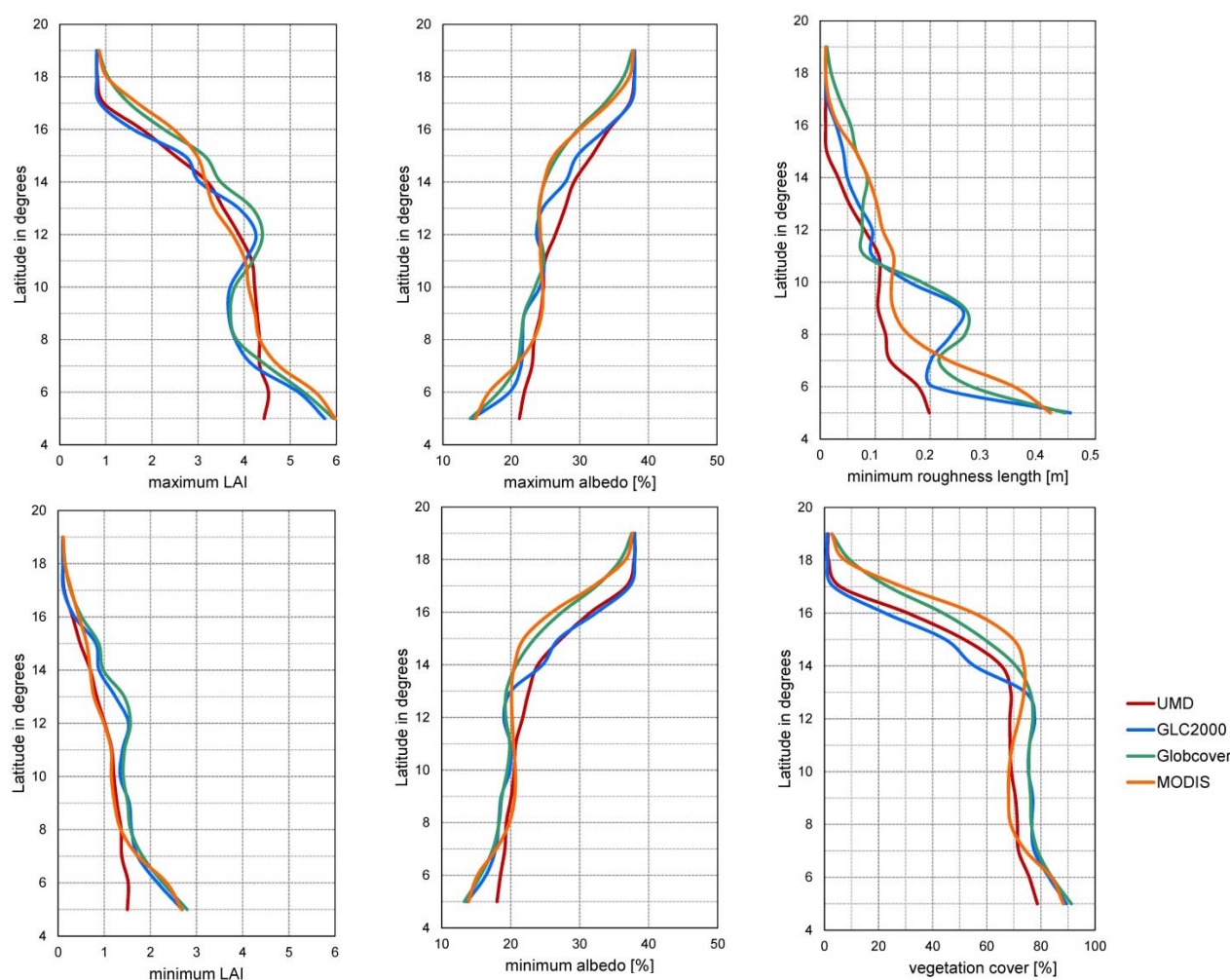


Figure 6: Latitudinal averages of selected land surface properties derived from the four generalized maps using the dataset in Table 2 for translation.

Local extremes are found for maximum LAI and minimum roughness length based on GLC 2000 and Globcover between approximately 8°N and 10°N (Figure 6). This pattern is contradictory to the expected vegetation structural zoning with respect to the continuously

increasing rainfall from north to south. The local extremes are related to the zone of ‘deciduous broadleaf trees’ and ‘shrubs’ in both maps. The reason for the local minimum of maximum LAI are the low values attributed to ‘shrubs’ (3.1) and ‘deciduous broadleaf trees’ (3.3) when compared to the high values attributed to ‘cultivated and managed’ (5.0). The local maximum for the minimum roughness length can be explained by the high roughness length attributed to ‘deciduous broadleaf trees’ (0.5 m) when compared to the class ‘cultivated and managed’ (0.05 m).

As the presented patterns do not suit the commonly presumed decrease of LAI and roughness length with latitude, the appropriateness of the global translation tables needs to be checked with respect to the particular conditions in West Africa. For LAI, this could be done using LAI time series which are derived from remote sensing data without involvement of land cover maps. In case such analyses confirm the doubts, these LAI time series could be used to redefine the translation tables.

4. Conclusions and outlook

The results of this study suggest several considerations when global information on land cover and related land surface properties is used as data source for regional climate modeling. First, the quality of global land cover maps considerably influences the delineated spatial patterns of land surface properties. It is thus important to carefully compare map accuracies and the appropriateness of classification schemes for the target region. Second, the standard values of land surface properties for global maps might not be appropriate for regional applications. Here, an option would be to redefine the land cover specific values of LAI, fraction of vegetation cover or albedo using statistics of adequate remote sensing products and by considering only the geographic region of interest. An even more reliable approach for the characterization of a number of land surface variables in climate modelling studies would be to directly use spatially explicit land surface parameters derived from remote sensing data without a detour via land cover maps. This option offers the additional advantage to consider both seasonal and inter-annual dynamics of the variables. This approach seems particularly promising for the variables LAI, albedo and fraction of vegetation cover where global remote sensing based datasets are already available. Here again, the quality of global datasets has to be checked carefully for the study region and has to be improved, where necessary.

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